Transitioning Results From Recent ONR WESTPAC Field Programs to Operational Use (IWISE Analysis Expansion)

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LONG-TERM GOAL

The long-term goal is to enhance our understanding of coastal oceanography by means of applying simple dynamical theories to high-quality observations obtained in the field. My primary area of expertise is physical oceanography, but I also enjoy collaborating with biological, chemical, acoustical, and optical oceanographers to work on interdisciplinary problems. I collaborate frequently with numerical modelers to improve predictive skill for Navy-relevant parameters in the littoral zone.

OBJECTIVES

The objective of this grant is to improve understanding of how the large-amplitude internal waves and tides in the northeastern South China Sea are generated via interaction of the barotropic tide with the ridges and islands in the Luzon Strait. In addition to the problem's inherent scientific interest, understanding the generation problem is essential for developing a forecast model to predict the wave characteristics in the deep basin and on the Chinese continental slope and shelf.

APPROACH

The approach is to particpate in a major ONR-sponsored field program in the Luzon Strait and northeastern South China Sea during 2010-2011. Called the Internal Waves in Straits Experiment (IWISE), the program is a logical follow-on to the Nonlinear Internal Waves Initiative (NLIWI) but will focus more closely on the generation problem, rather than on free propagation and wave dissipation during the earlier experiments. A large team of investigators from the U.S. and Taiwan is participating. Our primary collaborator in Taiwan is Prof. Y. J. Yang, now at National Taiwan University. He and Dr. Ramp were the co-leaders of cruises on Taiwanese vessels during the pilot study (June 2010) and the intensive observations program (IOP, August 2011). We have two key thrusts: Moored and shipboard observations south of Taiwan on the northern Heng-Chun ridge; and two far-field deep-water moorings near 18° 30'E to monitor wave arrivals. The Heng-Chun site has not been previously explored, even though numerical studies suggest it might be an important generation site. The far-field moorings will be combined with the PIES observations obtained by D. Farmer (UVic) and the source moorings of M. Alford (APL/UW) and J. Nash (OSU) to trace the progression of individual waves from the ridges to the deep basin. This activity is the subject of another planning letter presently under consideration by ONR. The program has an exciting numerical

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modeling component: We work especially closely with Oliver Fringer (Stanford) and Maarten Buijsman (NRLSSC).

WORK COMPLETED

The pilot study was quite successful and the results were described in previous annual reports and published in Ramp et al., [2012]. The IOP cruises were conducted during July – September 2011 from the OCEAN RESEARCHER III. These included a basin mooring deployment cruise during July (Figure 1), two cruises to the northern Heng-Chun Ridge during August, and a mooring recovery cruise during September. All the moorings were successfully recovered and the instruments returned full records of temperature (T), salinity (S), and current velocity (u, v). The preliminary results were presented at a workshop in Kaohsiung, Taiwan, during March 29-31, 2012. More advanced results were presented at seminars at National Taiwan University and National Sun Yat-sen University during November 2012. A presentation was made at the David Tang Memorial Session at the 2014 Ocean Sciences Meeting in Honolulu, HI. The data analysis from the IOP over the Heng-Chun Ridge is complete and a second manuscript has been submitted [Ramp et al., 2014]. The analysis of the deep basin moorings in concert with the PIES and near-field (source) moorings is ongoing.

RESULTS

During August 2011, a combination of a mooring, three anchor stations, and underway CTDs were used to study wave generation and propagation (Figure 1). Many more mode-2 waves were observed, most commonly just after the ebb tide turned. The mooring frequently observed packets containing 4-5 waves each in contrast to the pilot study wave which was believed to be solitary. The waves were characterized by a westward core velocity of order 50 cm s^{-1} between 100 – 200 m depth, and eastward return flow exceeding this amount above and weaker below. The isotherms were displaced upward by order 50 m in the top half of the waves and downward by a similar amount in the lower half. The wave packets were also clearly visible in the EK500 backscatter data and were associated with spectacular surface signatures. At times, several rows of alternating slicks and breaking waves were visible on the sea surface at the same time. The packets mostly propagated westward but other waves were occasionally observed propagating SSW, indicating at least two active sources nearby (Figure 2). The along-crest distances were short, only a few kilometers.

The turbulent dissipation (ε) was computed via the Thorpe scaling method. Large overturns of order 140 m with associated dissipation ε order 10^{-3} W/kg were observed in conjunction with two phenomena: roll-ups in the core of the mode-2 waves; and the high shear zone between the bottom-trapped tidal bore and the more quiescent water above. These features were present in both observations and models (Figure 3). The vertically integrated energy flux due to the mode-2 waves was order 30% of that due to the internal tide. The pressure work term u'p' was responsible for most of the flux in the wave, but zonal advection of kinetic energy was additionally important in the tide. The dissipation was very high, higher than that reported over deeper portions of the ridge [Alford et al., 2011] but smaller that the values in turbulent breaking mode-1 lee waves between Batan and Itbayat Island [Pinkel et al., 2012]. The high local dissipation and relatively small scales suggest the waves will not survive across the deep basin.

IMPACT/APPLICATION

Turbulent breaking internal waves in the mid-thermocline region have a profound effect on navigation and acoustic propagation. Improved understanding and predictive skill provides tactical advantage in that environment.

TRANSITIONS

Results have been transitioned to NRL Stennis, CNMOC, and NAVO via a personal visit by the PI. The PI retains a courtesy appointment at the Naval Postgraduate School and has regular contact with the U.S. Navy via officer-students and faculty there.

RELATED PROJECTS

The ONR PhilSea10 project [Worcester et al., in press; Colosi et al., 2013] may be useful in determining the internal wave propagation to the east of the Luzon Strait ridges. Please see associated annual reports for more details. The ONR/Taiwan NSC "sand dunes" project will investigate how nonlinear internal waves interact with the bottom. See separate annual report for details.

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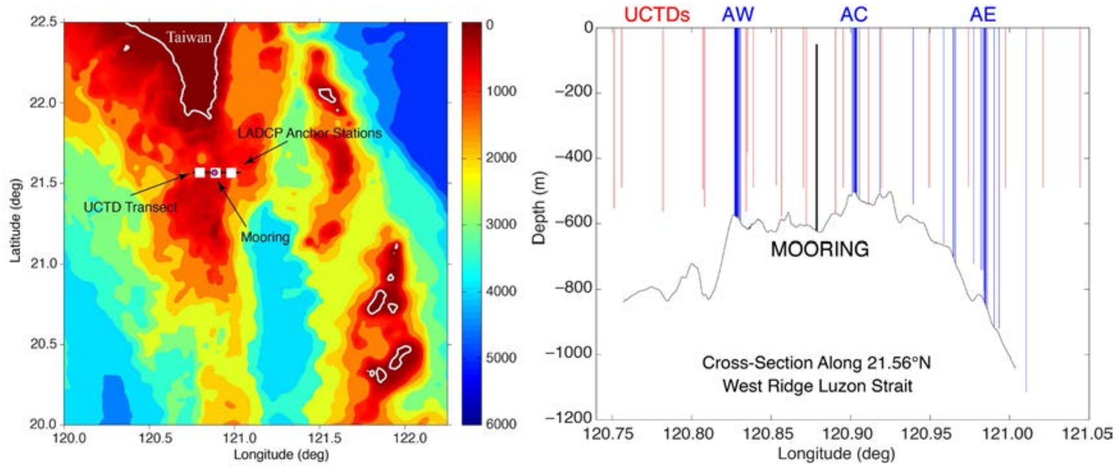

Figure 1. Location maps of the observations during the August 2011 field program. The 24-hour time series stations on the western, central, and eastern portion of the sill are indicated by AW, AC, and AE respectively.

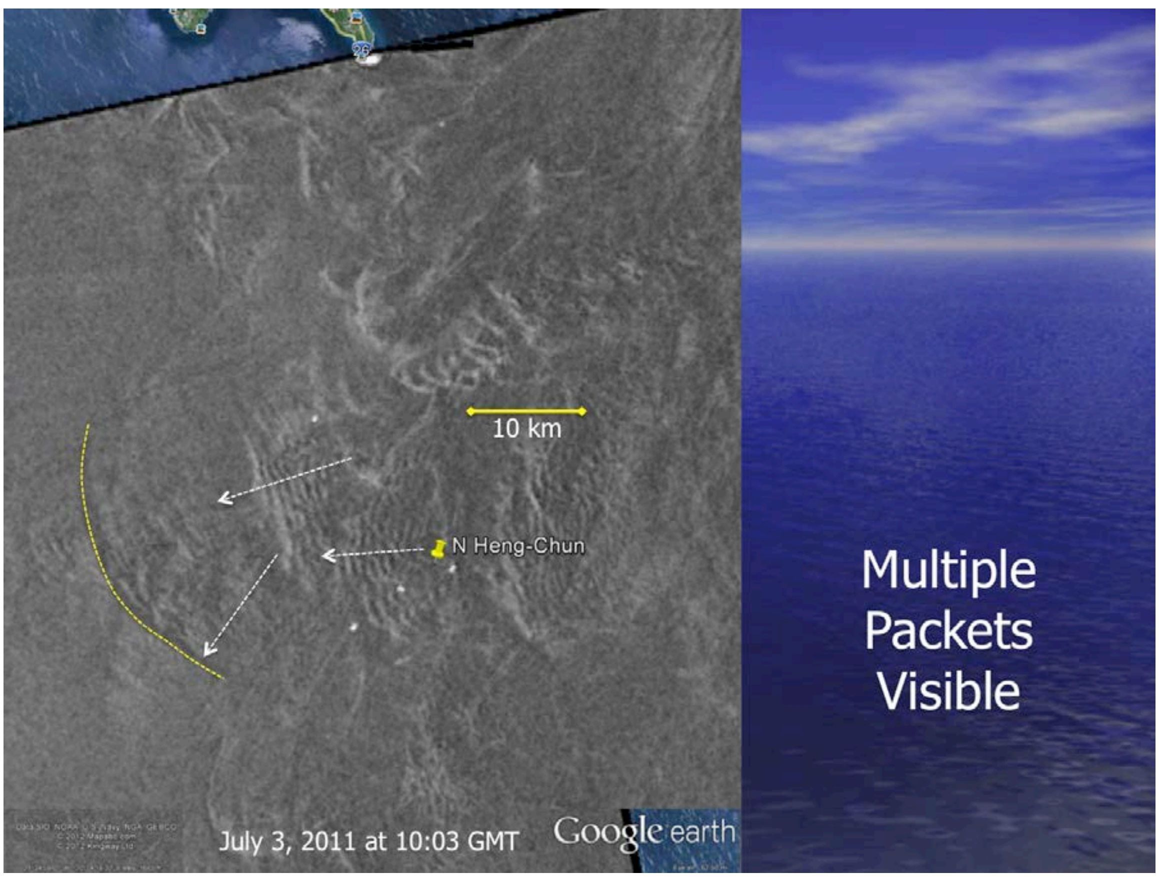

Figure 2. A SAR image summarizing the three types of waves observed in situ by ships and moorings over the Heng-Chun Ridge. A solitary wave and two packets with slightly different headings were observed.

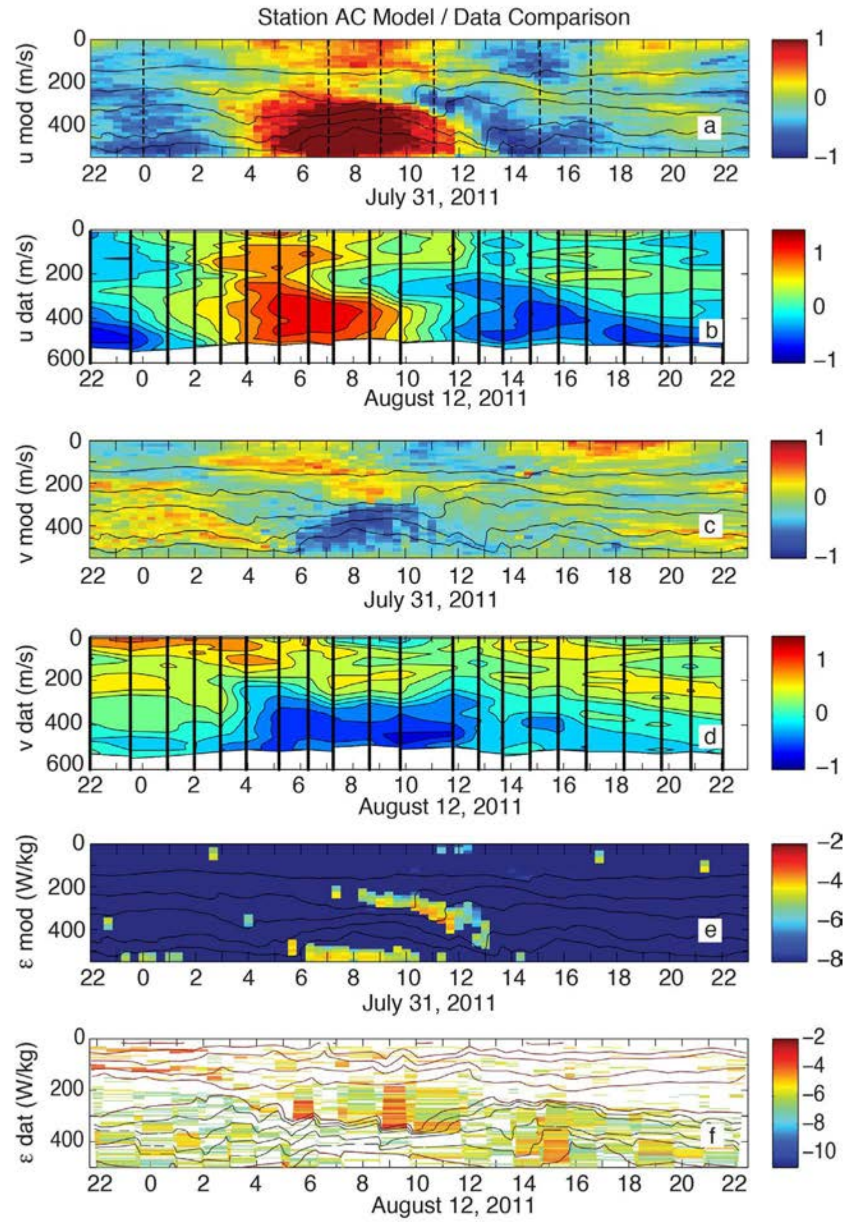

Figure 3. Model (MITgcm) / data comparisons over the northern Heng-Chun Ridge. July 31 and August 12 are from the same position in the tidal cycle. The u-component (a, b), v-component (c, d), and turbulent dissipation (e, f) are compared.